

THE WORLD OF CHEMISTRY

Program #19

METALS

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NARRATOR cont:

Metal machines make metal products, products that we wrap in metal, ship in metal, and use every day. Even food comes sealed in metal. We use metals to generate electricity, and then we transmit it across the country in metal wires. We make crowns with them, and coins with them. Of course, it's not surprising we've found so many ways to employ metals.

GRAPHIC: Periodic table

NARRATOR (MUSIC under):

About three-quarters of all known chemical elements are metals. The most abundant in the earth's crust are iron, aluminum, as well as calcium, sodium, potassium, and magnesium.

MONTAGE: Forging steel,
Egyptian painting, engine,
furnace, wires, factory shots

NARRATOR (MUSIC and NAT
SOUND under):

There seems to have been a direct relationship between the metals we used, how we used them, and civilization. Human progress was even marked in terms of stone, bronze, and iron. As our needs become more sophisticated and our abilities to produce metals and alloys become more advanced, our uses of metals become more specialized and diverse. But what is it about metals that makes them so useful? (cont.)

NARRATOR cont:

They conduct heat and electricity, and they're malleable and ductile. They can be pounded and drawn into many shapes. These are physical properties. What chemical properties do they have? Most metals are oxidized, and, in the process they give up electrons. But some metals are more reactive than others, some oxidize more readily.

DS in chemistry
classroom

DON SHOWALTER (SYNC):

I feel extravagant today. Let's try to burn a piece of platinum metal. So I'll light this burner, and here's my piece of platinum wire. I'll put it into the flame, and watch what happens. Well, you see that it's conducting the heat very well. In fact, it's getting red hot. But it's not oxidizing. Let me show you. I'll bring it outside and we let it cool. Again, the heat is conducted away from the metal very easily, and you see it's right back to normal. Thank goodness, huh? That's a lot of platinum. Now, we know other metals, though, oxidize readily. For instance, on this rusty old screw that I have here, we formed iron oxide. Iron oxidizes. Aluminum, you might not know, oxidizes even more readily than iron. So, in the process of competition for oxygen, which would win, iron or aluminum, in that process? (cont.)

(Air Script)

DON SHOWALTER cont:

Well I have a little experiment that I want to show you that will exhibit that. Inside this clay flower pot I have a mixture of aluminum powder and rust, iron oxide, and I have this magnesium strip here as a wick to initiate the reaction. Now, when we do initiate that, what we will see is that the aluminum will reduce the iron in the rust to form molten iron, and you will see a stream of molten iron come out of the bottom of that clay flower pot and be caught down in this system down in here. Now, there's a tremendous amount of heat given off there, so I'm just going to put on my face shield and get out of here, huh?

NARRATOR:

The difference in reactivity between the aluminum and the iron is accounted for by the difference in the electronic structure of the atoms.

DON SHOWALTER (SYNC):

Wow! That was quite a reaction, huh? Did you see that molten iron coming flowing out of there? Well, let me see if I can fish out some of the iron out of there. I've got this magnet. This is a thermite process that you just saw. That is used in welding, underwater welding, and railroaders use that for welding rails together. Oop! There's the nugget. Look at that. (cont.)

EQUATION

DON SHOWALTER cont:

Now, what you have seen is that aluminum has reduced iron oxide, rust, to iron metal.

DS at desk

DON SHOWALTER (SYNC):

To help us understand why metals have their characteristic properties, we're gonna have to look at their molecular make-up. Let's imagine now that these balls are metal atoms. I've got two different colors now so that you can see them. Metals certainly have all the same color. How would we stack them? Well, we would put the balls into the notches provided now by that lower layer. And this is, type of stacking is what we call the close-packed sort of structure, all the balls fitting into the notches of the lower layer. Now, this type of structuring is what allows metals to act as they do.

GRAPHIC: Atomic packing
in metals

NARRATOR (MUSIC under):

Metals are crystalline solids. In most cases, they have a fairly simple symmetrical structure of close-packed atoms. Notice here the second layer is formed by atoms resting in the depressions between the atoms of the first layer. In this case, the third layer is stacked exactly above the first. (cont.)

NARRATOR cont:

When a large number of metal atoms come together, forming a crystal, an interesting phenomenon occurs. When a valence electron from one atom feels the force field of the neighboring atoms, it leaves the original atom, briefly attaching to the other. It then moves to another, and yet another. We say these electrons are de-localized. They are free to wander throughout the entire metal crystal. We can picture the metal structure as a close-packed arrangement of positive metal ions immersed in a sea of negative electrons.

GRAPHIC: Electrical conductivity in metals

NARRATOR (MUSIC under):

When we apply an external electrical field, the de-localized electrons begin to drift from the negative to the positive side of the field. This is how they carry electrical current through the metal. It's this freedom of the electrons to move that also enables metals to conduct heat and reflect light.

MONTAGE: metals in many forms

NARRATOR (NAT SOUND under):

But why are metals malleable and ductile? The answer there, too, is found in the metal's structure. (cont.)

NARRATOR cont:

Because the electrons are free to move, the metal ions can slip over one another, as if riding on a cushion of electrons.

This slippage is facilitated by the presence of imperfections in the arrangement of the atoms.

MONTAGE: Rock blasting,
open pit mining, smelting
plant

NARRATOR (NAT SOUND under):

(SFX: Blast) But how, exactly, do we get metals from the earth? And what has to be done so we can put them to use? Iron is one of the world's most well-known and useful metals. The most common way of obtaining iron from the earth is open-pit mining, like this in Australia. If it is commercially feasible to extract the metal from the mineral mixture, we call that mixture an ore. Most iron ores are oxides. But occasionally iron is found as a sulfide mixed with other rocks. When a low-grade ore is mined, it must be physically separated from the other rocks and dirt. Only then is it ready to be shipped to a smelting plant where the metal will be extracted from its ore. Different metals come from different ores. But heat alone may not be enough to obtain metals from their ores. What else needs to be done?

DS in lab

DON SHOWALTER (SYNC):

We're going to have to add a reducing agent, and a common one that is used in this type of process is hydrogen gas. So I'm gonna put some of the iron oxide, the hematite, in this boat -- this is a little combustion boat -- and put it in there, and I want to do another experiment while we're doing this one to see if it will work. I'm gonna take some aluminum oxide and put it into this other boat here, in here, get enough of that powder in there. And what we'll do then is put these boats inside this combustion tube. All right, here is the hematite. Put the hematite in there, push it down the tube a little bit, hopefully not turning it over. There we go. Okay. And this is the aluminum oxide. We'll put it in there. What we're gonna do now is pass hydrogen gas over there and see if it's possible now to get the metal from the oxide. We'll see what happens. Close it up, and then I'll put some hydrogen gas from this source over here, run it through here and pass it over the metals. We'll turn that on. And now what we need to do, now we've got hydrogen passing over there, we need to heat this. Now, this probably will take some time, so I'm gonna heat it. (cont.)

EQUATION

DON SHOWALTER cont:

Well, we've heated it for quite awhile, passing hydrogen over there all the time. Let's see what happened, and I hope that -- yeah, it's cool, cool enough to handle. Let me take the cork out and see if I can grab those little boats out of there. The first one now that I'm gonna grab is aluminum oxide. It doesn't look much different than what it did originally. And in the second one now is the hematite. Let's see what it looks like. I'll grab a hold of it. Oh, it looks quite different. Let's look at that one. So what we can do, we can pass a bar magnet, I have a small bar magnet here, over that hematite, and if it did indeed reduce the iron, we should see some of that iron. Look at that! The iron was picked up right by the magnet.

Blast furnace

NARRATOR (MUSIC and NAT SOUND under):

Iron is most commonly produced in a blast furnace like this. The furnaces are huge, 30 meters tall and 10 meters wide at the base.

GRAPHIC: Animated
diagram of blast furnace

NARRATOR (MUSIC under):

Iron ore, coke, and limestone, calcium carbonate, are loaded into the top of the furnace. Then hot air, about 600 degrees Celsius, is forced through. As the carbon in the coke burns, the temperature rises even higher. Carbon monoxide, produced by the burning coke, moves up within the furnace, and both it and the carbon react with the iron oxides, reducing them to metallic iron.

MONTAGE: Blast furnace,
factory shots

NARRATOR (MUSIC and NAT
SOUND under):

At these temperatures, iron melts and sinks to the bottom of the furnace.

EQUATION

Meanwhile, the limestone decomposes to form calcium oxide, lime, which then reacts with the silicates or sand that might have been in the ore.

EQUATION

The calcium silicate which forms floats to the surface. But in the case of aluminum oxide, this type of reduction simply doesn't work. Aluminum couldn't be obtained in the laboratory because hydrogen just isn't a strong enough reducing agent. Electrical energy -- a lot of it -- is needed. The process is called electrolytic reduction and is barely over 100 years old.

Archival photograph,
aluminum plant shots,
power plant

NARRATOR (MUSIC and NAT
SOUND under):

Charles Martin Hall, an Oberlin College graduate, fresh out of school, invented the process in 1889. Prior to that, aluminum was so rare it was the metal of kings and queens.

EQUATION

Aluminum oxide is dissolved in a molten aluminum salt. The melt is then jolted with 130,000 amps of electrical current, reducing the aluminum oxide to metallic aluminum. The power requirements are enormous. One aluminum plant, in Frederick, Maryland, uses nearly a fifth of the total output of the nearby Potomac Edison Electric Company. Once aluminum has been purified, though, it takes only five percent of that initial energy to recycle it, making aluminum more economical.

RH in museum

ROALD HOFFMANN (SYNC):

We're in the National Building Museum in Washington. You can hear the sounds of renovation around me. That sculpture is actually a sheet metal exhibit, celebrating the wonderful properties of these materials which we use in our furnaces, in roofs, in duct work. (cont.)

ROALD HOFFMANN cont:

The sheet metals used in this exhibit include lead and tin-coated steel, zinc-coated steel that's called galvanized steel, copper, and brass. Now, copper, this beautiful shiny copper, is a reasonably pure metal, but the others are alloys, blends of two or more metals, or of a metal and a nonmetal. Since the beginnings of metallurgy, one of the first chemical technologies, it became clear that when one mixed two metals, that sometimes, not always, one obtained properties, melting points, strengths, that were superior to those of the components. The first such alloy, bronze, an alloy of copper and tin, was sufficiently important to have an age named after it. Soon after bronze came into use, people discovered another alloy, steel.

MONTAGE: Steel plant
shots

NARRATOR (NAT SOUND under):

Steel, more than any other metal, it drives the economy of the modern world. Most commonly, steel is made by the basic oxygen process. A furnace is filled with pig iron, limestone, and scrap steel. First, the impurities are burned off with a blast of oxygen.
(cont.)

NARRATOR cont:

Then carefully measured amounts of carbon are added, producing the alloy, steel, which is harder than iron. But how does the addition of small amounts of carbon make iron stronger?

GRAPHIC: Atomic
packing

NARRATOR (MUSIC under):

When you add small amounts of carbon to iron, as little as one part per thousand, the carbon atom, being smaller than the iron atom, fits into the interstitial spaces of the crystal. This small change in the structure of the iron crystal makes the slipping of iron ions more difficult. That's why steel is stronger than iron.

Steel plant shots

NARRATOR (NAT SOUND under):

This is Armco Steel in Baltimore. They make stainless steel here. Senior Metallurgist, Gerald Gelazela.

GERALD GELAZELA (VO/SYNC):

We make basic alloys, probably three or four dozen, but variations on those in which we put a little pinch of this, a little pinch of that, we can make two, three hundred varieties, more than Heinz Catsup. (cont.)

INTERVIEW: Gerald Gelazela,
Senior Metallurgist, Armco
Steel, Baltimore

SUPER: Gerald Gelazela

GERALD GELAZELA cont:

An alloy, basically some metal like base iron, to which you add some other chemical elements, like chromium, aluminum, nickel, copper, out of the periodic table. You may add a pinch of sulfur. That will give you machinability.

Steel plant shots

NARRATOR (NAT SOUND under):

This is 50 tons of molten iron. A pinch of chromium could be as much as half a ton, a pinch of boron could be as little as a few pounds.

INTERVIEW: Gerald
Gelazela cont.

GERALD GELAZELA (SYNC):

I'm still accused of being a witch doctor, so to speak, with the little pinches of this and the little pinches of that. But we do know what we're doing.

Steel plant shots

NARRATOR (NAT SOUND under):

The alloy they're making here is called Nitronic-32. It's a special alloy that will be woven into wire mats and cast in concrete. (cont.)

NARRATOR cont:

The concrete slabs will then be used to line the banks of the Mississippi River to control erosion. Simple variations in composition can result in a variety of alloys. From car antennas to turbine blades, we use these alloys every day. As alloys enter the mainstream of American life, the elements needed to make them gain special importance. But the United States doesn't have the naturally rich deposits of some ores that other countries do.

GERALD GELAZELA (VO):

Nickel primarily comes from Canada. The chromium may come from Rhodesia, Africa somewhere, or the Soviet Union in some cases.

Steel plant shots, rocket launch

NARRATOR (NAT SOUND under):

What if, suddenly, we couldn't import the metals we need to make our alloys, the chromium, or the nickel? How could we design and then substitute other alloys to manufacture the products we need? Just how dependent on these metals are we? The engines that propel this missile and the fins that guide it are made of superalloys, alloys that can withstand extreme temperatures and stress. Most commonly, they are made of iron and nickel, or iron and cobalt. Dr. Lance Davis.

INTERVIEW: Dr. Lance
Davis, Allied Signal
Corporation

SUPER: Lance Davis,
Allied Signal Corporation

DR. LANCE DAVIS (SYNC):

The source of cobalt is, is outside the United States, and, therefore, it is considered to be a strategic material, and you get exceptionally good properties in cobalt superalloys, but one would like to be able to produce the material as inexpensively as possible and not be susceptible to loss of supply due to changes in the political climate in another country.

Shots of jet airplanes

NARRATOR (NAT SOUND under):

But the uses of superalloys isn't limited to missiles and space exploration. This 80-ton airplane is about to land, and the wheels will have to support the weight and absorb the heat generated by the brakes. There are 3300 airplanes like this and each plane has an average of ten wheels. They cost over \$8,000 each and they do wear out. Salt corrosion and stress are the two major concerns.

INTERVIEW: Dr. Lance
Davis cont.

DR. LANCE DAVIS (SYNC):

The particular driving force and our own interest in aluminum has to do with various types of applications where corrosion resistance and high-temperature resistance could stand to be improved.

MONTAGE: Aluminum and
aluminum research

NARRATOR (MUSIC and NAT
SOUND under):

This is aluminum foil. Chemically and physically, it's very different from household foil. It's an alloy containing iron and silicon and other elements. In ordinary casting like this, the metal cools slowly and the other elements can combine, crystallizing together. Weak points would form and cracks could develop. But researchers here at Allied Signal Corporation found if they cooled the molten alloy quickly, up to a hundred degrees in a fraction of a second, the aluminum would solidify before the crystals could form. This created a new aluminum alloy. Its enhanced strength came from the iron and the good heat resistance came from the silicon.

INTERVIEW: Dr. Lance
Davis cont.

DR. LANCE DAVIS (SYNC):

That really is the forte of the material scientist, is to try to control, to use changes in chemistry and processing to produce a material that has the unique properties that are required for a particular application. It all depends on the particular application that you have in mind and, and the properties that are required for that particular application. But there are many ideas and dreams that people have today which are ultimately limited by the availability of materials.

SUPER: METALS

MONTAGE: Skyscrapers,
construction, auto plants,
program graphics, working
with metals and metal tools,
mining, factory shots

NARRATOR (MUSIC under):

To review: Metals are used to form the framework of our cities, but there are many metals with many different uses, from jewelry to steel beams. Three-quarters of all known chemical elements are metals. The most abundant are iron and aluminum. Metals are malleable and ductile. They can be folded, pounded, and drawn into many shapes. And they conduct heat and electricity. (cont.)

NARRATOR cont:

These properties derive from the microstructure. At the micro level, metals are crystalline solids with a close-packed structure of atoms. Within the crystals, the valence electrons are delocalized and free to wander throughout the crystal. While all metals have many chemical and physical properties in common, they can be vastly different. So techniques for obtaining metals from their ores vary. Chemical reduction is used to obtain iron, and electrolytic reduction is needed to produce aluminum. Alloys are blends of metals and other elements which result in new materials with new properties and uses. Some countries don't have the ore deposits others do, so shortages or costs promote the development of new alloys.

RH in museum with
chemical models

ROALD HOFFMANN (SYNC):

It's been a long road full of art, craft, and science, from copper and bronze to a new nickel-iron super-alloy, and there's more. So far we've talked only about the mechanical properties of metals and alloys, their strength, their malleability. But there is more about metals that makes them valuable to human beings. (cont.)

ROALD HOFFMANN cont:

There is their luster -- think of mirrors -- or magnetism, the unique features of iron as a magnet which made compasses and navigation possible, or, in our century, electrical conductivity. Copper is an extraordinarily good conductor of electricity when it's fashioned into wires. At the beginning of this century, people discovered a new phenomenon in some metals and alloys. These metals conducted electricity without resistance, essentially endlessly. But they did so only at very low temperatures, where it was not useful to make any devices from them. Something changed around 1986. First one material was made, then another one. These were high-temperature superconductors. Let me show you one of them. It has in it yttrium, a rare earth metal -- that's the blue balls -- barium, an alkaline earth metal -- that's the white balls -- our old friend, copper, and ubiquitous oxygen a real cross-section of the periodic table. This material is really a superconductor and at a high enough temperature that I think we will soon see wires and magnets fashioned from it. There are new metals and alloys with special properties, still waiting to be discovered.

Credits, Closing Montage, Closing Music

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